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Technical Report No. 181

Tests of Third Climate Version Physics in the UK Mesoscale Model

by

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December 1995

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NWP Development Division

December 1995

1. Abstract

A new package of physics for the climate model has been proposed as the next 'frozen' version. These changes were designed to address a number of known biases in the climate model, rather than to address problems in the mesoscale forecast model. This Report summarises briefly the changes that are proposed and the results from a set of trials in the mesoscale model (MM). Individual components have been tested using a number of representative cases, and the results used to select a subset of components for operational implementation. Results from the individual components and the combined package are presented here.

2. Components of the Third Climate Version Physics

The following components of the third climate version (3CV) physics were tested:

i) Negative q local correction.
The MM currently uses the global correction scheme to correct areas of negative humidity generated by the advection scheme. This conserves moisture but can redistribute it over a wide area. A new version exists which applies a local correction. While more realistic, the code is relatively expensive, and the problem is not thought to be significant in the MM. However, the scheme was tested using a small number of cases.

ii) Changes to precipitation scheme.
A number of changes have been made connected with the large scale cloud and precipitation schemes. These are:

a) Modified LS PPN scheme including

- Precipitation rates are determined accounting for the distribution of cloud water contents within the cloudy part of the grid box as implied by the distribution of total water used in layer cloud scheme.
- Modified treatment of ice precipitation - changes the ice fallout calculation to improve long time-step behaviour.

b) In principle, the 3 CV physics includes a change to the SW radiation scheme which incorporates an effective radius for water drops determined from MRF/UMIST

parametrization using specified aerosol values with a land sea contrast. This is obtained in user interface by selecting microphysics ON in the SW radiation scheme options. However, this change is not available for version 1B of the SW radiation code, which the mesoscale model uses, and so has not been included in the trials.

c) FOCWWIL change.

d) Corrected treatment of the evaporation of rain and snow (mainly including a pressure dependency)

The FOCWWIL change has been tested on its own in the past, with very little impact, while the effective radius code is not available in the version of SW radiation used in the mesoscale model. These changes have therefore been grouped together on the assumption that a) and d) will have the main impact. One area of interest not relevant to the other models is the impact of fog forecasts where snow is present. This has been found to be very sensitive in the past to the treatment of ice fallout and its interaction with large scale cloud.

iii) 3B boundary layer.
Version 3B of the boundary layer code applies a restriction of the rapidly mixing term in the BL scheme to below convective cloud base. This has been found to be of benefit in the climate model, but has been tested in the past in isolation in the MM and found detrimental.

iv) Modified Diffusion around steep orography.
The 3CV package includes a modification to horizontal diffusion to turn it off around steep orography. In fact, the original version of this has already been found to be of benefit in the MM and has been implemented operationally. Tests here are restricted to tests of the new version which makes the test for steepness stronger (so that diffusion is turned off more often) as compared with the 'operational' configuration.

v) Correction to boundary layer code.
A minor bug has been found in the boundary layer code which increases by one the number of levels used to define the boundary layer depth, and so effectively increases the mixing lengths used in stable conditions. While this should be corrected, it has been found that the corrected scheme produces inferior results in configurations with lower vertical resolution than the MM. This has been overcome by specifying greater mixing lengths. The impact is likely to be much less in the MM because of its greatly increased boundary layer resolution.

vi) Correction to specification of saturation humidity mixing ratio.
The saturation humidity mixing ratio is computed in numerous places in the model. The computation is approximate (it ignores the vapour pressure term in the denominator) and a more accurate computation has been shown to have benefits in larger scale models (primarily in areas where the saturation vapour pressure tends to be large, i.e. the tropics).

3. Testing Strategy

It is clear from the above that not all the components are expected to have an impact in all meteorological situations. At the very least, it is unlikely that the changes to the cloud and precipitation schemes will have an impact in clear sky cases. Tests were therefore performed by choosing a number of cases which were representative of particular conditions. The conditions of interest included:

- nocturnal clear sky
- fog, both land radiation fog and sea fog
- summer convective showers
- winter convective showers
- strong winds
- widespread frontal rain
- widespread dynamic snow
- stratus and stratocumulus

On the whole, the cases were chosen to be typical, in a subjective sense, of MM performance, in that they were not so poor, because of gross errors in the larger scale forcing, that any improvement found would be misleading, but not so fortuitously good that improvement would be difficult.

4. Assessment methods

Each case was rerun using the current operational configuration, to ensure a clean comparison, and the same period then run using the modified code. Since the main interest was in the physical development during the forecast, only three hours of data assimilation were included using the original ACobs files. When the full package, to be discussed below, was tested two additional sets of runs were performed including a full day's cycle of data assimilation. The forecasts were assessed subjectively, with particular emphasis on precipitation distribution and type, cloud cover and fog. Objective verification was performed using the SAS based mesoscale verification code which uses up to 270 surface sites where data are available.

5. Cases Used

We chose a large cross section of cases to test the various contenders for the package and other model changes. Of course, it was not necessary to run each potential upgrade on *every* case. Each test was only run on cases which had synoptic features that would particularly show up any deficiencies (or otherwise) in the test in question.

Listed below are the cases used, each with a brief synoptic description-:

5/8/94 06Z - Clear sky case; slack mainly northwest, later northeasterly airstream, with a high centre building over and to the northwest of Ireland.

24/8/94 06Z - Disorganized summer convection; unstable mainly southwest, later

westerly flow around a shallow low centred over northern Britain.

8/10/94 06Z - Fog case; slack flow around a ridge in south, with a weak, slow-moving cold front lying northeast-southwest over northern England & North Wales.

14/10/94 00Z - Fog; slack east to southeast airstream over England around a ridge extending west from an anticyclone over the near continent.

17/1/95 06Z - Strong winds and front; very intense depression close to northwest Britain driving an active cold front eastward.

15/2/95 06Z - Organised winter convection; deeply unstable southwesterly around a major vortex centred near northern Scotland.

17/2/95 06Z - Stratocumulus; unstable west to northwesterly gradually stabilising as a ridge approached from the west.

22/2/95 06Z - Frontal case; deep low centre just north of Scotland driving an active cold front southeast across the country.

2/3/95 12Z - Snow; rapidly developing wave depression in southwest approaches then tracking across S. Wales and southern England.

28/3/95 00Z - Snow; ridge giving way as a deepening depression moves southeast across Northern Ireland to the Midlands and E. Anglia.

17/5/95 18Z - Fog area around Manchester; a fairly slack north to northwesterly, with weak ridging developing.

30/5/95 06Z - Spurious sea fog in English Channel; slack, unstable southwesterly, veering to northwest behind slow eastward moving trough.

13/6/95 00Z - Cloudy northeasterly; anticyclone over northwest Britain giving a cool, cloudy northeasterly over much of England.

The cases used for each component are shown in the table below. Each component is given a three letter identifier. A list of the descriptions follows.

DIFF: Model runs as operational with the new Mk II diffusion scheme.

PPN: Model runs as operational with the new version (3D) of the precipitation scheme, the FOCWIL change and the corrected treatment of the evaporation of rain and snow.

3BL: Model runs as operational with the new (3B) boundary layer scheme which restricts the rapidly mixing term to below convective cloud base.

SHC: Model runs as operational with the correction to the saturation humidity mixing ratio added.

BLC: Model runs as operational with the correction to the boundary layer added

QNG: Model runs as operational with the addition of a locai negative Q correction.

Below is a table of all the cases run for each trial.

	DIFF	PPN	3BL	SHC	BLC	QNG
5/8/94			x		x	
24/8/94				x		
8/10/95	x			x		
14/10/95	x			x		
17/1/95		x				
15/2/95	x					x
17/2/95					x	
22/2/95		x		x		
2/3/95		x				x
28/3/95		x				
17/5/94	x					
30/5/95	x			x	x	
13/6/94			x		x	

6. Summary of the Subjective Assessment of Individual Components

Many of the components had little or no impact on the forecasts, and even those which did, the impact was often restricted to one or two cases and limited aspects (such as precipitation distribution). For this reason, rather than describe the impact on a case by case basis, only those cases with significant impact have been described below, together with any overall impressions where relevant.

Negative 'q' correction: Two precipitation cases were examined. No impact found in either of the two cases.

Precipitation scheme modifications package: four cases were examined. These were: an active front, strong winds and two snow cases. For the front no significant differences were found. In the strong winds case there was a marked increase in dynamic rainfall rates in the boundary areas but no significant differences elsewhere. The first snow case (2nd March '95 - intense depression moving east over southern England) showed no differences in the general precipitation area, just somewhat more intense showers off southwest England in the later frames. The second snow case (28th March '95 - frontal wave moving southeast) had a less intense, more fragmented forward edge to the precipitation area. This was a significant positive impact as can be seen in Figures 1 to 3.

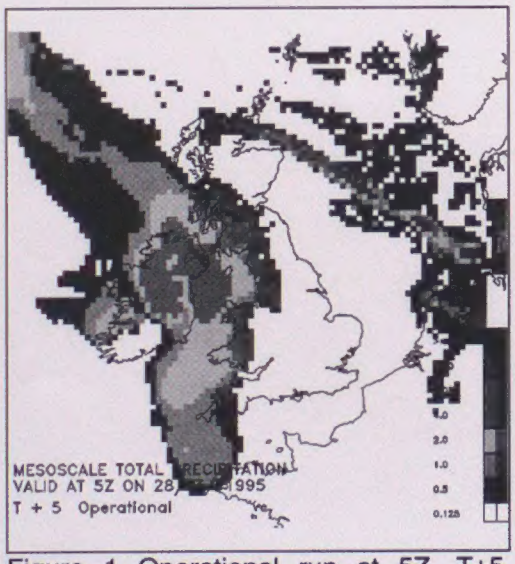

Figure 1 Operational run at 5Z, T+5, 28/3/95

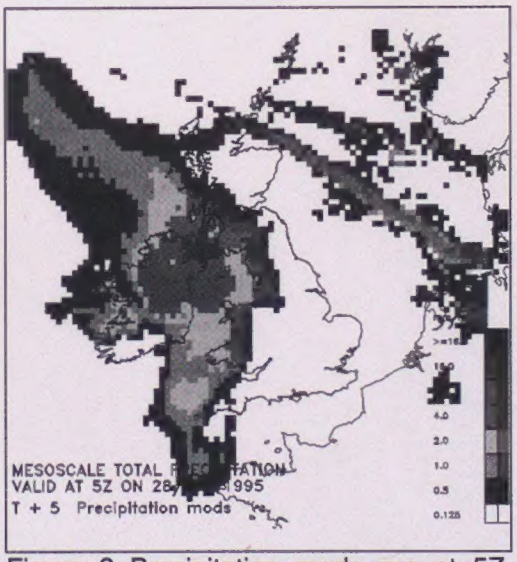

Figure 2 Precipitation mods run at 5Z, T+5, 28/3/95

Figure 3 Frontiers Radar Image at 5Z, 28/3/95

3B Boundary Layer: The two runs examined were: a summertime cloudy northeasterly and a clear sky case. In the latter there were no significant differences but for the cloudy northeasterly there was a clear detrimental impact in that there was considerably less cloud with the new scheme, for a case where the operational model run already had too little cloud. Later precipitation frames also verified less well than the original operational run. This modification has been looked at before, with similar results.

New (MKII) Diffusion Scheme: three land-based fog cases, one spurious sea fog case and one organized winter convection case were tested. Only small impacts were found, as much of the benefit of improved diffusion was already present in the operational run. A little more fog and stratus was apparent in places in one fog case and in another the fog was lifted about an hour earlier. These changes appear to be a small benefit. On the other hand there was a slight increase in the extent of the spurious sea fog. The winter convection case cloud frames had slightly less low cloud downwind of high ground which is very difficult to verify.

Saturation Specific Humidity Correction: Five cases were re-run: two for fog, an active front, disorganized summer convection and a spurious sea fog case. Any differences were *very* small. There were just some *slightly* larger areas of fog and low cloud for two of the fog cases, probably beneficial.

Boundary Layer Correction: The four cases examined were: extensive stratocumulus, spurious sea fog, summertime cloudy northeasterly and a clear sky case. On the whole only insignificant differences were found, but there was a tendency for more fog in two of the cases. These were generally small and insignificant differences, except in the spurious (Channel) fog case, where the new run had little impact on the spurious fog itself, but produced an increase in the fog probability from 10 to 30% over quite a large area of the North Sea. The operational model output eventually produced a similar result but some 5 or 6 hours later. The earlier production of the higher fog probabilities appears to verify well since satellite imagery showed that a large area of fog and/or stratus did develop, and just where the model had predicted it to be.

Figure 4 Impact of boundary layer correction on fog probability at 8Z, T+2, 30/05/95. Operational left, Modified right.

Boundary Layer Correction & New Mixing Length: Two of the above four cases, including the sea fog one, were reassessed with both the corrected BL code and a modification to increase the mixing lengths used in stable conditions to a value which has been found to compensate for the deterioration produced by introducing the correction to the LAM. In this case the results were effectively identical to those with the boundary layer correction alone, so the modified mixing lengths were not pursued.

7. Summary of the Objective Assessment

The impact on objective statistics was, in many cases, vary small. In order to highlight the overall impact, statistics have been generated combining all the cases used for each component. Even so, in many cases, the impact was negligible, so only the main impacts are highlighted below.

Negative 'q' correction: No impact.

New (MkII) diffusion scheme: No significant impact, just a *slight* improvement in the hit/false alarm rate for fog at T+3 to T+9 for the 14/10/94 case.

Precipitation scheme modifications: A slight beneficial impact on cloud base errors, especially after T+3 for greater than half cover, but a small increase in the false alarm rate of stratus and fog, mainly after T+15. There is also a small, beneficial knock-on effect with inland surface temperatures.

3B boundary layer: No significant overall impact, but the cloudy northeasterly case

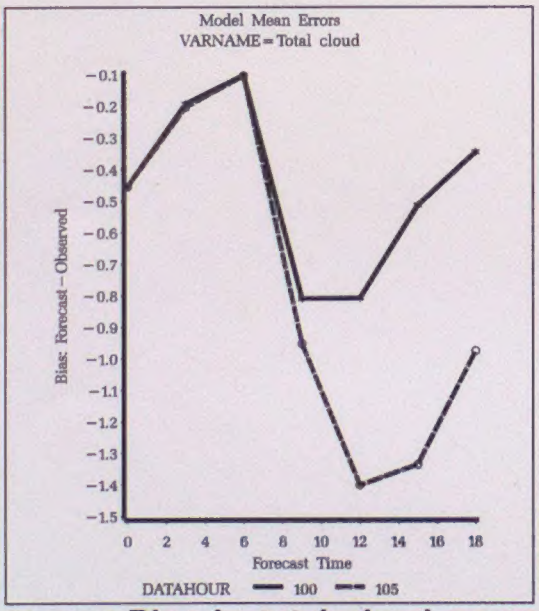

Figure 6 Bias in total cloud cover for 13/6/95 case. 100=Operational, 105=3B boundary layer.

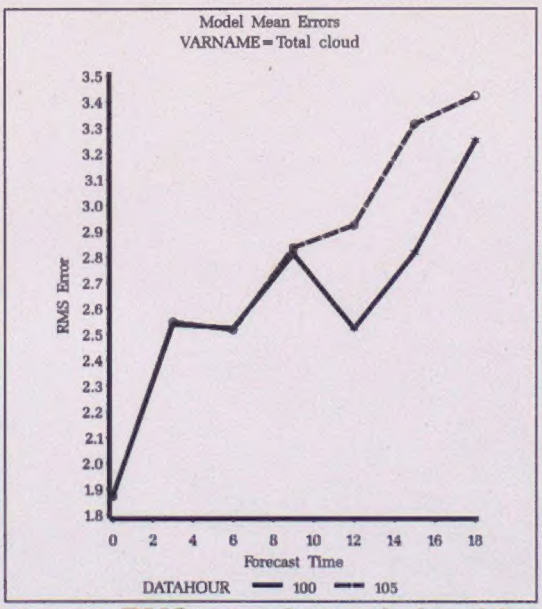

Figure 5 RMS error in total cloud for 13/6/95 case.

alone showed a near doubling of the negative cloud amount bias after T+9, confirming the subjective appraisal thereof. Figures 5 and 6 show a considerable degradation in the forecast of total cloud amounts for 13/6/95 using this new boundary layer scheme (identifier 105) compared with the operational (100).

Saturation specific humidity correction: No impact.

Boundary layer correction: No significant impact.

Boundary layer correction & new mixing length combined: No significant impact.

8. CPU Usage

A table of CPU usage for each case is shown in Appendix A. The overall message from this is that the main impact on CPU would come from the modified precipitation scheme, with some increase (about 6%) also coming from the negative q correction and a little (3%) from the saturation specific humidity change. Appendix B gives some results for the combined package, as described in the next section.

9. Conclusions and Recommendations for Combined Package

The impact of the components is very largely neutral: the major reason for operational implementation would be compatibility with 3CV physics. In spite of this, there seems little reason to implement the 3B boundary layer, which has a negative impact (also found in larger scale forecast models), or the negative q correction, which has no impact but costs CPU time. The rest of the package appears to have small but beneficial impacts. In the event, the improved diffusion code has not been included in the 3CV package, and so will not be included here, but it is recommended that it should be included at a later date if the code becomes incorporated into the UM - it's impact is very small but should be beneficial. The remaining components have been combined to form a package and tested using the methodology required by the WGDOS TSG for mesoscale upgrades.

In summary, the full package comprises components ii, v and vi in section 2 above.

10. Full Package Cases

These series of tests concluded the autumn upgrade trials. They were intended as a final trial featuring all the mods. and other changes that were deemed useful to go into the package, and a series of runs were set up to test them.

There were two types of mesoscale model run. The first were two "whole day" (long) runs as described below:

"**LONG**": continuous assimilation runs to produce four forecast during a day. The cases were:

20/4/95- Convection case; low just off northeast Scotland giving a slack but unstable, mainly northwesterly.

2/3/95 - Snow case; rapidly developing wave depression in southwest approaches tracking across S. Wales and southern England.

In order to save confusion, the precise rerun procedure is detailed below:

21Z => 18Z (next day) Full 18hr run + 3 hours assimilation.
00Z => 03Z (using dump from previous run) 3 hours assimilation.
03Z => 12Z (next day) (using dump from previous run) Full 30hr run + 3 hours assimilation.
06Z => 09Z (using dump from previous run) 3 hours assimilation.
09Z => 12Z (next day) (using dump from previous run) Full 24hr run + 3 hours assimilation.
12Z => 15Z (next day) (using dump from previous run) 3 hours assimilation.
15Z => 18Z (next day) (using dump from previous run) Full 18hr run + 3 hours assimilation.

The others were ordinary reruns as taken from the operational dumps, boundary conditions, etc. They were:

"**NORMAL**" runs:-

13/07/94 00Z- Spanish plume; ridge to the west, low pressure over near continent & North Sea, slack northerly at low levels, southwesterly aloft.
13/09/95 00Z- Radiation fog; weak ridge over the country with a slack flow.
17/01/95 06Z- Strong winds and front; very intense depression close to northwest Britain driving an active cold front eastwards.
16/08/95 06Z- Clear summer day; anticyclone covers the U.K.
22/02/95 00Z- Clear winter night following a front; deep low centre just north of Scotland driving an active cold front southeast across the country.
07/08/95 18Z- Stratus; anticyclone building to the north of the country, with an increasingly brisk north to northeasterly over most parts.
23/08/95 06Z- Frontal case; quite active front across north & west Britain, moving steadily east.

Assessment was along the same lines as above - both subjective assessment of the diagnostic output charts and objective assessment from surface stations.

10. Summary of the Subjective Assessment of the Full Package Runs.

For the most part the impact of the package was very small and neutral. Only two of the 9 cases examined showed significant differences between the operational runs and those incorporating the full package. These differences were on the whole beneficial to the forecast.

For the post-frontal unstable westerly case of 22nd February '95 the upgrade showed a definite tendency correctly to keep nocturnal showers going much further inland, e.g. reaching the Birmingham area from the Cambrian mountains, and Yorkshire over the Penines as can be seen in Figures 7 to 9.

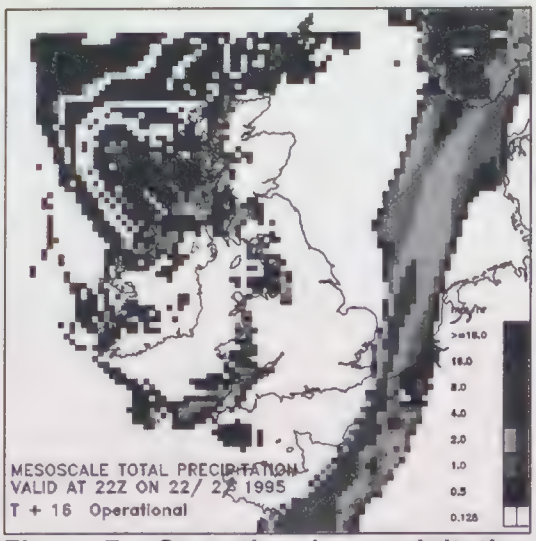

Figure 7 Operational precipitation distribution, 22Z, T+16 22/2/95

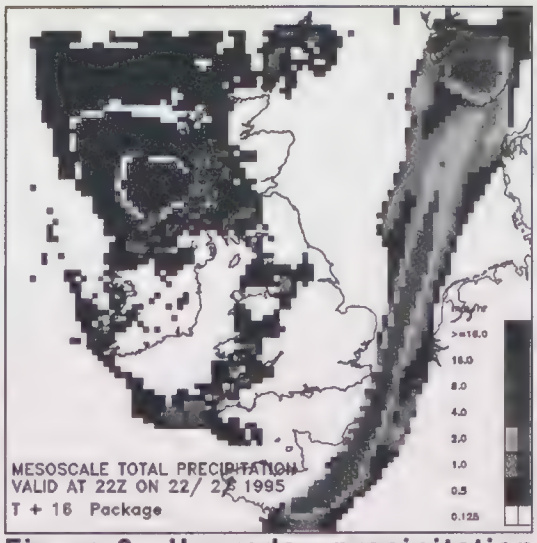

Figure 8 Upgrade precipitation distribution, 22Z, T+16 22/2/95

Figure 9 Frontiers Radar rainfall 22Z 22/2/95.

The widespread, heavy snow case of the 2nd March '95 was, however, double-edged: the upgrade had better-placed rain/snow boundaries and was a little colder over land in the snow area, which also verified better. On the other hand there were considerably larger areas of fog probability, mainly over land, as can be seen in Figures 10 & 11. This was found to be a lowering of the cloud base under large-scale snowfall, in itself not a serious problem but the upgrade package did produce rather larger, more intense areas of large-scale snowfall over windward high ground, some of which was spurious or overdone.

Figure 10 Operational cloud and fog cover, 3Z, T+3 2/3/95.

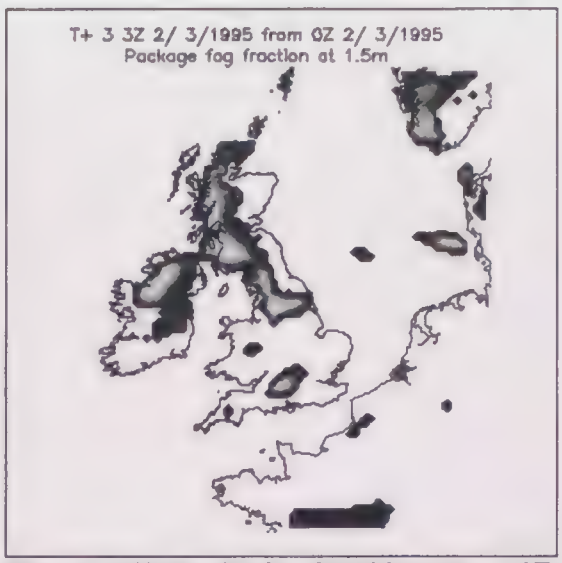

Figure 11 Upgrade cloud and fog cover, 3Z, T+3 2/3/95.

11. Summary of Objective Assessment of the Full Package.

On the whole, no significant differences between the verification of the operational runs and those of the upgrade package. But both the 17th January strong winds/front case and the 2nd March snow case showed some improvement in cloud base errors, but for the latter there were also more false alarms for fog/stratus.

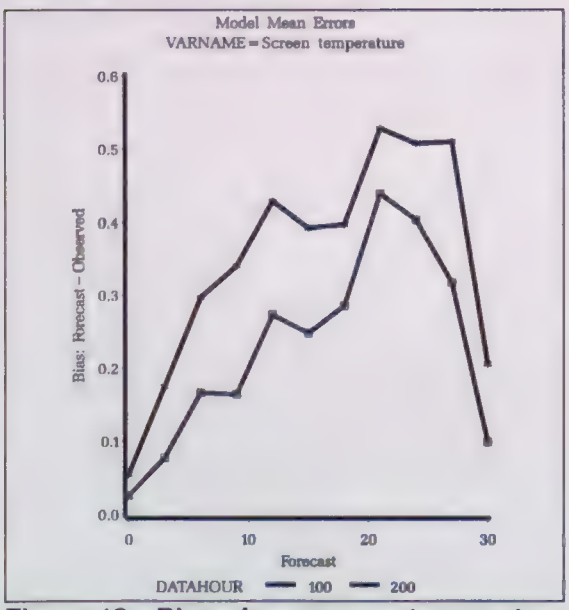

Figure 12 Bias in screen temperature averaged over all cases. 100 = operational, 200=upgrade.

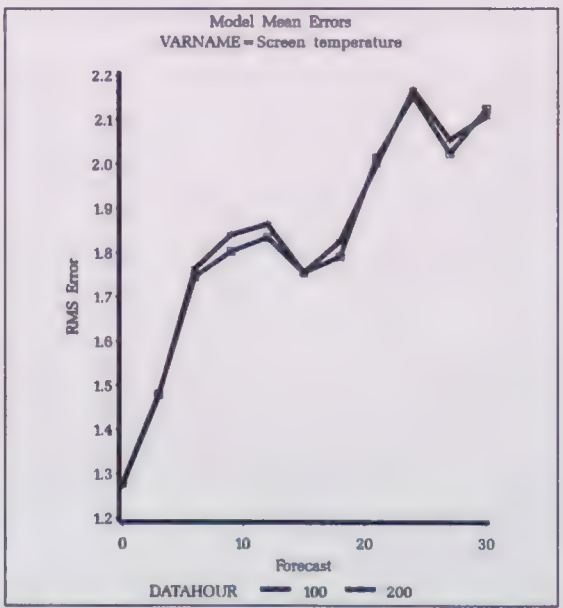

Figure 13 RMS error in screen temperature averaged over all cases. 100 = operational, 200=upgrade.

The merged verification (all runs/cases) also showed somewhat better cloud base verification, especially for more than half cover, along with the increase in the false alarm rate for fog fog/stratus. A slight (~ 0.1 deg. Celsius) improvement was apparent in the surface temperature errors. Some collated verification statistics for all the cases merged follows:

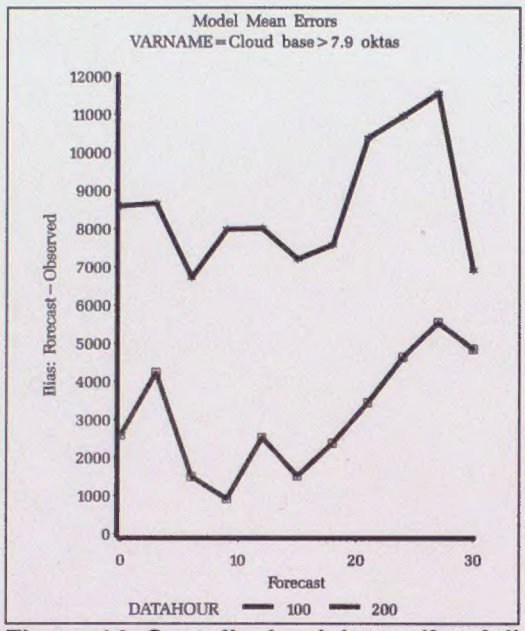

Figure 14 Overall cloud base (for full cover) bias. 100 = operational, 200 = upgrade.

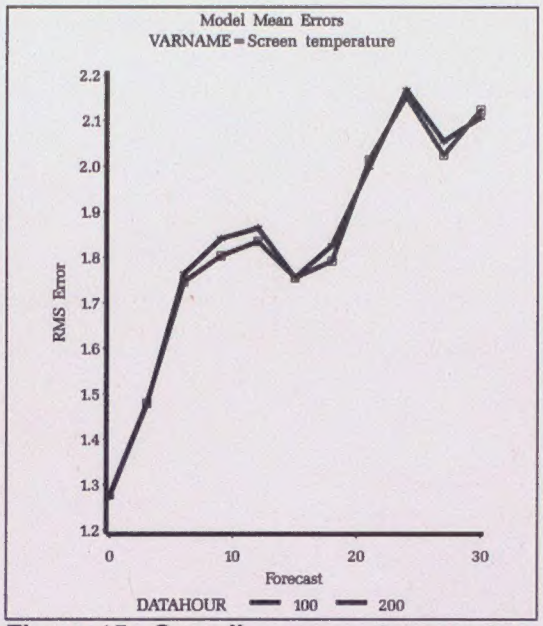

Figure 15 Overall screen temperature RMS errors. 100 = operational, 200 = upgrade.

NOTE:-The upgrade runs are denoted by boxed points, the operational by crossed.

Overall the signal is good, although in Figures 16 & 17 it can be seen that the relative humidity errors are increased slightly.

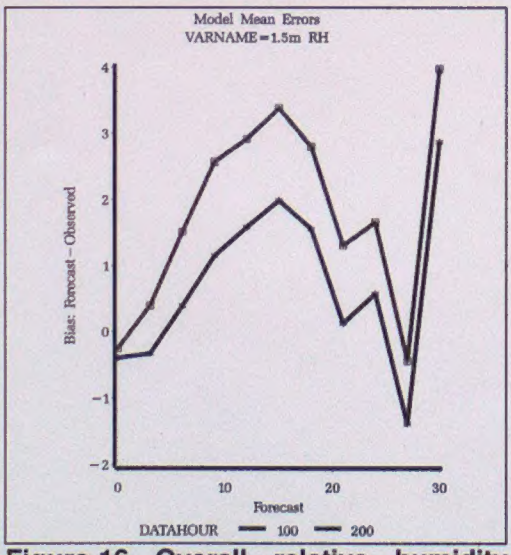

Figure 16 Overall relative humidity bias. 100 = operational, 200 = upgrade.

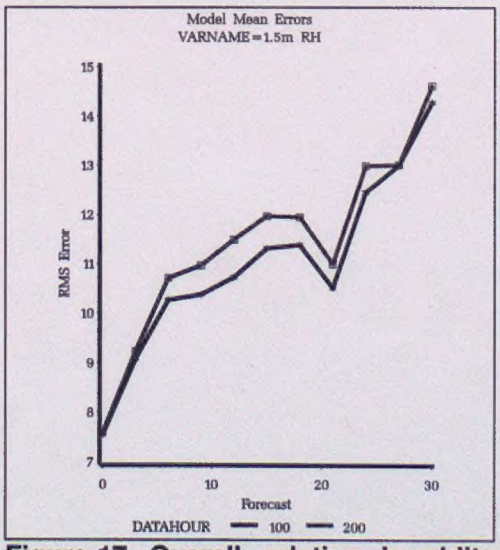

Figure 17 Overall relative humidity RMS errors. 100 = operational, 200 = upgrade.

12. Cost

The overall package is approximately 8% more expensive in CPU, when averaged over all cases, with more efficient optimisation of the code (see Appendix B).

13. Conclusions and recommendations.

Most of the 3CV package has a small but positive impact on the mesoscale model. The main exception is the restriction of the rapidly mixing boundary layer to below convective cloud base which has been omitted from the proposed mesoscale upgrade package. Some of the benefits, though small, are in areas where previous changes have had little impact, particularly the definition of snow areas and encouraging the penetration of showers inland later in the day in showery northeasterlies, so they are to be welcomed. The main disadvantage is a significant increase in CPU usage.

Appendix A. CPU Times for Individual Components

Table of CPU times per run per case, with total averaged CPU increase.

	OPR	DIF		3BL		SHC		BLC		QNG	
	CPU	CPU	%inc	CPU	%inc	CPU	%inc	CPU	%inc	CPU	%inc
5/8/94 6Z	2063.0	x	x	2065.2	0.1	x	x	2060.2	-0.1	x	x
8/10/94 6Z	1989.5	1997.1	0.4	x	x	2053.1	3.2	x	x	x	x
14/10/94 0Z	1293.1	1304.7	0.9	x	x	1322.4	2.3	x	x	x	x
15/2/95 6Z	2126.5	2156.8	1.4	x	x	x	x	x	x	2272.2	6.9
17/5/95 18Z	1409.8	1412.9	0.2	x	x	x	x	x	x	x	x
30/5/95 6Z	2151.6	2162.7	0.5	x	x	2224.1	3.4	2114.4	-1.7	x	x
2/3/95 12Z	1771.2	x	x	x	x	x	x	x	x	1883.5	6.3
17/1/95 6Z	2146.6	x	x	x	x	x	x	x	x	x	x
22/2/95 0Z	1372.4	x	x	x	x	1424.1	3.8	x	x	x	x
28/3/95 0Z	1401.2	x	x	x	x	x	x	x	x	x	x
13/6/95 0Z	1344.6	x	x	1349.5	0.4	x	x	1316.6	-2.1	x	x
17/2/95 6Z	2113.0	x	x	x	x	x	x	2120.9	0.4	x	x
24/8/94 6Z	2194.5	x	x	x	x	2269.2	3.4	x	x	x	x
% increase	**n/a**	**0.7 %**		**0.2 %**		**3.2 %**		**-0.9 %**		**6.6 %**	

NOTE:- There are no statistics for the Precipitation changes, since the mod did not vectorise properly with the standard compile options and gave an increase of CPU of approximately 17%. Some reruns were done with the full package using the "aggressive vectorisation" option and these statistics are presented in the next appendix.

Appendix B. CPU Times for Individual Components

Table of CPU times for full package cases

	OPR	FULL	
	CPU	CPU	%inc
17/1/95 6Z	2158.3	2376.6	10.3
2/3/95 0Z	1421.4	1511.4	6.5
%incr	**n/a**	**8.4 %**	

There was a problem with the LS_PPN scheme using vast amounts of CPU time (a factor of ten more than the old scheme). After the conclusion of the tests, it was discovered that aggressively optimising the code helps to solve this problem. Two more runs were performed using the "aggress" compiler optimiser option and these results appear above.
Time was limited, so only the two runs were performed.